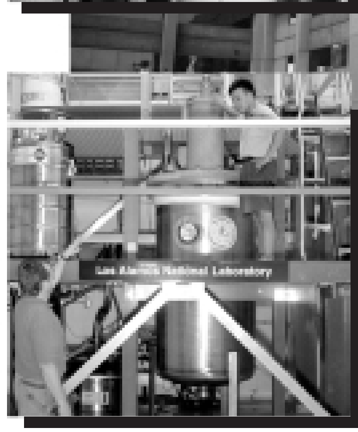
USER FACILITIES

CHAPTER 2

The research activities described in Chapter 1 are supported by the extensive facilities of the National High Magnetic Field Laboratory. Each of the consortium partners—Florida State University (FSU), the University of Florida (UF), and Los Alamos National Laboratory (LANL)—offers outstanding resources for users, but collectively, the three sites offer members of the worldwide science and engineering communities unprecedented opportunities to explore science at the extremes of magnetic field, pressure, and temperature.

University of Florida

Florida State University



Los Alamos National Laboratory

The portion of the laboratory located at FSU in Tallahassee is housed in a modern, 330,000 sq. ft. complex dedicated to research and technology related to high magnetic fields. Housed at this site are superconducting, resistive, and hybrid magnets, along with instruments for nuclear magnetic resonance, electron magnetic resonance, Fourier transform ion cyclotron resonance mass spectrometry, and geochemistry. The NHMFL Pulsed Field Facility is located at LANL in New Mexico; and the High B/T (magnetic field/temperature) Facility and the magnetic resonance imaging and spectroscopy assets of the laboratory are located at UF in Gainesville. In addition to the "hardware" assets of the laboratory (presented in the six tables that follow), the close proximity of visiting users to the distinguished NHMFL faculty and the affiliated faculty at the three institutions sets the stage for very productive collaborations and cross-disciplinary scientific exchanges.

Continuous Field Facility

The DC facilities in Tallahassee have a unique and extremely powerful infrastructure—a 36 MW DC power supply with ripple and noise approaching 10 ppm and an overload capacity to 40 MW for an hour or 68 MW for several minutes. The complex also has a very low vibration cooling system that is especially important for experiments with very small signals. The Continuous Field Facility also has extensive support capabilities, including a machine shop, an electronics shop, and computer support.

Table 1. General Purpose Magnets and Research in Tallahassee.

Resistive and Hybrid Magnets

Field (T), Bore (mm)	Power (MW)	Supported Research
45,32 *	24	Magneto-optics (ultraviolet through far infrared); microwave conductivity; millimeter wave spectroscopy; magnetization; specific heat; transport; high pressure; low to medium resolution NMR; EMR; dependence of optical and transport properties on field, orientation, etc. Temperatures from 40 mK to 800 K.
33,32 §	19	
30,32	20	
27,32 to 50	15.7	
25,52	19	
24.5,32	13.1	
20,195	20	

* Under development
§ Highest performing system of its kind in the world

Superconducting Magnets

Field (T), Bore (mm)	Power (MW)	Supported Research
18/20,52	20 mK to 2 K	Magneto-optics (ultraviolet through far infrared); microwave conductivity; magnetization; specific heat; transport; high pressure; low to medium resolution NMR; dependence of optical and transport properties on field, orientation, etc.
17.5/19.5,52	0.4 K to 300 K	
15,45	10 mK to 1 K	

The continuous field magnet systems available or under development include resistive, superconducting, and hybrid magnets (Table 1). The world's highest continuous field resistive magnets—33 T in a 32 mm bore—are located in this facility, as well as 24.5 T, 32 mm bore, high homogeneity magnets that have proven to be extremely useful tools for magnetic resonance research. A 25 T, 52 mm bore Bitter magnet with 1 ppm homogeneity and stability is available for magnetic resonance experiments. It was developed and is being improved with funding from the NSF and the Keck Foundation. A very large bore—20 T, 195 mm—magnet is available for superconducting magnet coil tests, ion cyclotron resonance, two-axis sample rotation, long-path magneto optics, very high temperatures, and other experiments that will not fit into the other magnets. The 45 T, 32 mm bore, hybrid magnet has been tested to 44 T and is expected to be operational in the summer of 2000. This magnet comprises a 14 T, 610 mm, warm bore, cable-in-conduit, superconducting outsert with a 24 MW, 31 T, resistive insert.

Instrumentation to support the kinds of research listed in the table is available along with people to assist scientists with their experiments. Contact the people and see the web sites listed at the end of this chapter for more information.

Magnetic Resonance Facilities

The NHMFL's Center for Interdisciplinary Magnetic Resonance was established in 1994 to support studies in nuclear magnetic resonance (NMR), magnet resonance imaging (MRI), electron magnetic resonance (EMR), and ion cyclotron resonance (ICR). A unique feature of CIMAR is the large-scale integration of NMR, MRI, EMR, and ICR spectroscopies. Cross-fertilization among these fields is facilitated at the laboratory in several ways through a broad-based external and internal users program. The magnetic resonance program spans all three NHMFL sites.

Table 2. CIMAR Facilities in Tallahassee.

Frequency	Field (T), Bore (mm)	Homogeneity	Measurements
1066 MHz §	25, 52	10 ppm	Solid state NMR
900 MHz *	21.1,110	1 ppb	NMR
833 MHz §	19.6,31	100 ppb	Solid state NMR
720 MHz	16.9, 31	1 ppb	Solution state NMR
600 MHz	14, 89	1 ppb	MRI and solid state NMR
600 MHz	14, 52	1 ppb	Solution state NMR
500 MHz	11.75, 50	1 ppb	Solution state NMR
400 MHz	9.4, 89	1 ppb	Solid state NMR
400 MHz	9.4, 89	1 ppb	Solution state NMR with high T_c probe
300 MHz	7, 50	1 ppb	Solution state NMR
300 MHz	7, 89	1 ppb	Solid state NMR
up to 7 THz §	30, 32	100 ppm	CW EMR
700 GHz §	25, 52		Multifrequency CW EMR
470 GHz §	17, 61	10 ppm	Multifrequency CW EMR
240 GHz §	9, 89	10 ppm	Transient EMR
400 GHz *	14, 89	3 ppm	Transient EMR
23 GHz		3 ppm	K-band CW EPR
9 GHz		1 ppm	X-band CW EPR
	15-17,110 *		ICR
	11,220 *	1 ppm	ICR
	9.4,220 §	1 ppm	ICR
	7, 150	1 ppm	ICR
	6, 150	1 ppm	ICR
	3,150	10 ppm	ICR

*Under development
§ Highest performing system of its kind in the world

NMR User Facility in Tallahassee

The NMR systems available in Tallahassee are shown in Table 2. Some specific applications available to users are listed below.

- **High Resolution Spectra in Low Homogeneity Magnets**: Intermolecular zero quantum coherence spectroscopy has been demonstrated in the NHMFL's 25 T Keck magnet leading to linewidths of 0.03 ppm.
- **Stray Field Imaging**: Imaging in the 75 T/m stray field of the 19.6 T superconducting magnet at the NHMFL leads to spatial resolution approaching 1 µm even for samples with large magnetic susceptibilities.
- **Hyperpolarized Xenon-129 Facility**: Hyperpolarized Xe-129 is available for a wide variety of applications from surface chemistry and microimaging to flow measurements.
- **Double Rotation NMR for Observing Quadrupolar Nuclei**: DOR capability for obtaining high resolution spectra of quadrupolar nuclei is available at fields up to 16.9 T and soon will be available at 25 T.

- **High Field ^{19}F Solid State NMR**: Double resonance H/F at 19.6 T and triple resonance H/F/X at 14 T are available for static and magic angle spinning spectroscopy, respectively.
- **Magic Angle Turning at High Magnetic Fields**: Magic Angle Turning in an H/X/Y probe at 14 T is available for high spectral resolution and enhanced polarization transfer.
- **^{2}H Wideline Spectroscopy of Short T_{2e} Samples**: 2H sites suffering from short T_{2e} relaxation cannot be obtained at low field due to extensive acoustic ringing, but at high field the acoustic ringing is damped permitting spectral observation.
- **Observing Low Gamma Nuclei**: Many important nuclei in materials such as semiconductors, electrode materials, glasses, and catalysts have low gyromagnetic ratios and low sensitivity. Spectroscopy up to 19.6 T and 25 T is available at the NHMFL.
- **Dynamics in Deuterated Proteins**: A technique for characterizing protein dynamics from commonly used perdeuterated protein samples has been developed, based on ^{2}H relaxation contributions to adjacent ^{13}C nuclei.
- **GAMMA**: This spectral simulation platform supported at the NHMFL is used worldwide. The platform has been exceptionally useful as a very sophisticated spin physics tool, and is now being developed as an educational tool.
- **PFG NMR Diffusion Measurements**: Three axis gradients up to 100 G/cm in a wide bore 14 T magnet and Z-axis gradients up to 1000 G/cm are available. A variety of capabilities from diffusion tensor imaging to velocimetry and electro-osmotic flow are available.
- **Imaging, Microimaging and *In Vivo* Spectroscopy**: Gradient probes with microcoils having a diameter of 500 μm and susceptibility matching are available. Probes for observing thin slices of perfused tissue are also available. Field strengths up to 17.6 T (89 mm bore) and bore diameters up to 400 mm (11.75 T) will soon be available.
- **Structural Biology with Solid State NMR**: Double resonance spectroscopy up to 14 T for the observation of orientational constraints in membrane proteins is available. Triple resonance MAS spectroscopy up to 14 T for the observation of distance and torsional constraints is also available.

The NHMFL, in partnership with Intermagnetics General, is developing a 900 MHz (21.1 T) high resolution magnet system for NMR. This wide bore (100 mm ID) system is expected to be completed in late 2000 and will provide the highest field large bore NMR system in the world. The design of this system will also serve as a platform for the incorporation of a high temperature superconducting insert magnet that will provide the combined field of 25 T (1.067 GHz).

For more details about the facilities available for NMR in Tallahassee, see the contact information at the end of this chapter.

EMR User Facility in Tallahassee

Electron magnetic resonance, which includes ESR, EPR, and antiferromagnetic resonance, is conducted in both resistive and superconducting magnets. Highlighting the EMR program are the 700 GHz spectrometer developed with the Keck 25 T resistive magnet, the 470 GHz Continuous Wave (CW) EMR machine, and the recently developed 240 GHz transient instrument. The 470 GHz CW machine is now using quasi-optical techniques and has sensitivity comparable with commercial X-band spectrometers (10 GHz). The 240 GHz transient machine will allow the study of fast phenomena in the sub nanosecond range, which is of paramount interest in photochemistry and photosynthesis, for instance.

The EMR in-house and user program has been very successful for two principal reasons:

1. The increased resolution available at high field, which has been used for studies of photosynthetic systems, fullerenes, and fullerene based compounds.
2. The availability of multi-high frequency/high magnetic field instruments for the study of large zero field splitting systems, such as single molecule magnets and metal ions.

For more details about the facilities available for EMR in Tallahassee, see the contact information at the end of this chapter.

ICR User Facility in Tallahassee

The centerpiece of the ICR program is a 9.4 T, 1 ppm, 220 mm warm bore, shielded superconducting Oxford magnet system. This is the highest performance system of its kind in the world, offering users unparalleled opportunities to identify and characterize large molecules including peptides, proteins, oligosaccharides, and nucleic acids. A 7 T, 150 mm bore system has been optimized for high sensitivity analysis of dilute solutions in complex matrices (e.g., biological fluids). Integrated chromatography allows sample cleanup, concentration, and separation to occur online. In addition, ICR systems at 11 T and 17 T are under construction.

For more details about the facilities available for ICR in Tallahassee, see the contact information at the end of this chapter.

Geochemistry Facilities in Tallahassee

The mass spectrometry facility includes a better-than-Class 500 wet chemistry clean laboratory. This lab is used for the separation and purification of all elements that are analyzed by solid source mass spectrometry. In addition, the facility has two vacuum lines used for separation and purification of samples for light stable isotope analysis. The facility has three mass spectrometers providing a unique combination of ionization techniques: sputtering and thermal ionization as well as ionization in a plasma source. The Lamont Isolab, the only one of its kind in the United States, is outfitted with a Daly detection system and five Faraday cups, and has thermal ionization and secondary ionization capability. This instrument is used for analyses of Th, Hf, and Hg isotopes in environmental samples.

The facility includes a fully automated, 7 collector, Finnigan MAT 262, mass spectrometer equipped with a retarding potential quadrupole for increased abundance sensitivity and a 13 sample turret. Ion counting systems are located both before and after the retarding potential quadrupole. This second mass spectrometer is be used for Sr, Nd, Pb, and U isotope ratio analyses by positive-ion thermal ionization and Re and Os by negative-ion ionization, as well as most isotope dilution analyses.

The third mass spectrometer is a high resolution inductive coupled plasma mass spectrometer (ICP-MS). This instrument represents a new generation of ICP-MS as the mass analyzer is a magnetic sector instead of a conventional quadrupole magnet resulting in superior mass resolution and transmission. This instrument has a single electron multiplier as detector. The instrument includes an inlet system that allows dry plasma running conditions. This instrument is used for low level trace element analysis of a variety of environmental materials as well as isotope dilution analysis.

For more details about the facilities available for Geochemistry in Tallahassee, see the contact information at the end of this chapter.

Materials and Magnet Component Characterization Facilities

These facilities provide testing and analysis services to NHMFL magnet design teams as well as industrial and academic researchers. The Materials Characterization Laboratory provides precise measurements of electrical resistivity, thermal expansion, and superconductor critical current. Mechanical properties such as tensile, compressive, fatigue, and shear strength can also be measured.

Table 3. Sector Magnet Mass Spectrometers.

Type of ionization	Mass Analyzer Configuration	Detection Systems	Measurement	Sample Introduction
Thermal and sputtering	E-M-D1-E-D2	FC-EM	Isotope ratio	Solids and chemical separates
Thermal	M-D1-E-D2	FC-EM	Isotope ratio	Chemical separates
Thermal-plasma	M-E-D	EM	Isotope abundance	Solutions

There are three servo-hydraulic test machines for performing mechanical tests over a range of temperatures (1.8 K to 400 K). Two superconducting magnets can provide background fields of up to 15 T in conjunction with mechanical and electrical tests. E-mail *walsh@magnet.fsu.edu* for more information.

The Large Magnet Component Test Facilities (LMCTF) are dedicated to testing the critical components for large superconducting magnets. Particular emphasis has been given to capabilities for testing stability, ac losses, and stress effects of composite cables for large magnet applications, such as the superconducting outsert of the 45 T Hybrid, as well as magnets for fusion, for superconducting magnetic energy storage (SMES), and for high-energy physics. The facilities, moreover, have also been useful for testing other components such as high-current cryogenic current leads with high temperature superconductor (HTS) segments, terminals and joints for large conductors, and HTS bus bars. Superconducting magnets are available as follows: a 400 mm cold bore solenoid with 8 T maximum field; a 50 mm aperture, 1 m long, 7 T dipole (used for AC loss measurements); and a 2 m cold bore, 4 T solenoid (part of a Navy SMES development program). E-mail *miller@magnet.fsu.edu* for more information.

The NHMFL at Los Alamos National Laboratory

Pulsed Field Facility

LANL is home to the NHMFL's Pulsed Field Facility because of that laboratory's unique facilities for the production of pulsed electrical power. The Pulsed Field Facility is supported by a capacitor bank of 1.2 MJ and a motor generator capable of delivering an energy pulse of 600 MJ.

In fall of 1999, the NHMFL Los Alamos facilities were relocated to a new building. This move was accompanied by an extensive redesign of the user support infrastructure. In the new building, the NHMFL–Los Alamos is configured for future growth by fully exploiting the freedom to time-multiplex pulsed magnet experiments. The Long-Pulse and Short-Pulse User programs are now located in separate buildings and, for the first time, short-pulse experiments can operate completely independently of one another.

A variety of pulsed magnet systems are available at NHMFL–Los Alamos (Table 4) including 50 T and 60 T capacitive-driven magnets with 24 mm and 15 mm bores, respectively. All of these systems are equipped with an assortment of dilution refrigerators (available for the 50 T, 24 mm bore), ^{3}He, and variable temperature inserts, and instrumentation that supports transport, magnetization, high pressure, and optics studies. Four magnet stations, collaborative opportunities, and user support are available.

The 60 T, 32 mm bore, Long-Pulse Magnet (100 ms flat-top) is now available. Besides being the most powerful of its class in the world, this magnet is also the first of its kind in the United States. It promises to be a significant new research tool. One of the key features of this magnet is the great flexibility offered to users to tailor the magnetic field profile to the demands of the experiment. The magnet can be pulsed every hour, and the magnetic pulse shape can be changed from pulse to pulse at user demand. Pulse shapes include "flat top" pulses at 60 T for 100 ms; 50 T for 200 ms; and 40 T for 500 ms. Smooth magnetic field sweeps from 60 T down to 0 T are also available. The user-controlled pulse shape capabilities enable thermodynamic measurements, such as heat capacity to 60 T. Recently M. Jaime, R. Movshovich *et al.* measured the effect of high magnetic field on the energy gap of $Ce_3Bi_4Pt_3$ by means of heat capacity measurements to 60 T (paper to be published in *Nature,* 2000).

In addition to systems currently available, a non-destructive 100 T (15 mm bore, 20 ms) pulsed magnet is being developed by the NHMFL and LANL as a jointly-funded effort of the U.S. Department of Energy and the National Science Foundation.

A 19.5 T superconducting magnet with 52 mm bore is also available. This magnet is equipped with a variety of probes, including: dilution refrigerator, variable temperature inserts, and high temperature insert allowing experiments from 20 mK to 600 K. This magnet not only serves as a staging magnet for calibration purposes for pulse field experiments but also as an excellent tool to measure magnetotransport, heat capacity, thermal-expansion and magnetostriction in a wide temperature range.

For more details about the NHMFL facilities at LANL, see the contact information at the end of this chapter.

Table 4. General Purpose Magnets and Research in Los Alamos.

Pulsed Magnets

Field (T), bore (mm)	**Rise/Decay (ms)**	**Supported Research**
50, 24 40, 24	6 / 15 80 / 500	Magneto-optics (ultra- violet through near infrared). Magnetization and magnetotransport from 350 mK to 200 K. A plastic dilution refrigerator is also available for the 50 T, 24 mm bore magnet. Pressure capability is also available.
60, 15	6 / 15	All the above (except magnetization) (100 ms flat-top at 60 T)
60, 32§	1000/2000	User-controlled pulse shape allows measurements of specific heat

Superconducting Magnets

Field (T), bore (mm)	**Supported Research**
19.5, 52	Same as pulsed fields, plus magnetovolume and specific heat. Temperatures from 20 mK to 600 K
9, 32	Magneto-optics (ultraviolet to near infrared)
5T, 52 (Split coil)	Ultrafast magneto-optics

§ Highest performing system of its kind in the world

The NHMFL at the University of Florida, Gainesville

High B/T Facility

The NHMFL commissioned a high magnetic field and low temperature facility in 1997, known as the High B/T Facility. This facility provides researchers with the opportunity for studying phenomena that require simultaneous high magnetic fields and low temperatures. Current facilities provide 15.5 T with homogeneity of 50 ppm over 10 mm DSV and temperatures as low as 0.5 mK with a cooling capacity of the order of 10 nW. This cooling capacity allows users access to high B/T conditions for several weeks at a time to carry out a variety of experiments on a given sample. Values of the ratio of magnetic field to temperature with B/T up to 3 x 10^4 T/K are available to users. Many new phenomena that require the establishment of high spin polarizations or high magnetizations, including nuclear magnetism, magnetokinetics, polarized quantum fluids, quantum-confined structures, and non-Fermi liquids, may be explored in this research facility.

For more details about the High B/T Facility, see the contact information at the end of this chapter.

Table 5. Instruments available at the High B/T Facility.

Equipment	Feature	Usage
125 A bipolar magnet power supply	Positive to negative current ramp without a reversing switch	Superconducting magnet
180 MHz RF SQUID	High sensitivity, low noise	Magnetism measurements
DC SQUID	High sensitivity, low noise	Magnetism measurements
DHI Pressure Calibration System, PG 7601	Ultra high accuracy	Pressure calibration
LCR Meter HP 4263B	Mutual inductance option	Magnetic thermometry in the range 10 to 1000 mK
DSP Lock-in amplifier, EGG726	Built-in oscillator with frequency sweep	Helium viscosity and temperature measurements

Magnetic Resonance Imaging and Spectroscopy

NHMFL user facilities for high field magnetic resonance imaging and spectroscopy (MRI/S) are available in Gainesville. Table 6 shows the large array of instruments available. Among these instruments are two world premiere systems and other rare or unique capabilities:

1. The world's first 11.7 T, 40 cm magnet reached field in February 2000. The console is being interfaced and the machine is expected to be available by the summer.
2. The world's second 750 MHz wide bore imager/spectrometer (the first is in Holland), and the first with microimaging capability, also reached field in February and is now capable of imaging.
3. The 4.7 T, 33 cm system has the first animal system phased array capability in the United States.
4. The first transcieve phased array coils for spine and prostate imaging are now available on the 3 T, 80 cm human imaging system.

This large range of instruments offers high field NMR and MRI capabilities on a variety of biological systems ranging from biochemical solution studies, through imaging of single cells, isolated tissues, and animal models, leading to human research studies. Technological developments underway at UF involve the construction and testing of novel rf coil hardware, including microcoils, phased array coils (transcieve and receive only), and novel high frequency/large volume coils. Extensive rf coil construction capabilities are available to outside users.

UF Brain Institute

The NHMFL has established strong ties with the UF Center for Structural Biology and the UF College of Medicine, and has consolidated its MRI efforts at the UF Brain Institute. For more information on MRI/S facilities and the UFBI, see the contact information at the end of this chapter.

Table 6. CIMAR Facilities in Gainesville.

Frequency	Field (T), Bore (mm)	Homogeneity	Measurements
750 MHz	17.5, 89	1 ppb	Solution state NMR &MRI
600 MHz	14, 51	1 ppb	Solution state NMR &MRI
500 MHz	11.75, 400	0.1 ppm	MRI/S of animals
500 MHz	11.75, 50	1 ppb	Solution state NMR
500 MHz	11.75, 50	1 ppb	Solution and solid state NMR
200 MHz	4.7, 330	0.1 ppm	MRI &NMR of animals
125 MHz	3, 800	0.1 ppm	Whole body MRI &NMR

The NHMFL Proposal Review Process

Members of the worldwide science and engineering communities may access all NHMFL facilities, generally without cost, through a peer-reviewed proposal process. Contact one of the people listed below for further information.

Continuous Field Facilities
Tallahassee, FL
http://www.magnet.fsu.edu/user/facilities/dcfacilities/index.html
Bruce Brandt
Phone: 850-644-4068
Fax: 850-644-0534
brandt@magnet.fsu.edu

Magnetic Resonance Facilities
Tallahassee, FL
http://www.magnet.fsu.edu/science/programs/cimar/

Louis-Claude Brunel (EMR)
Phone: 850-644-1647
Fax: 850-644-1366
brunel@magnet.fsu.edu

Tim Cross (NMR)
Phone: 850-644-0917
Fax: 850-644-1366
cross@magnet.fsu.edu

Alan Marshall (ICR)
Phone: 850-644-0529
Fax: 850-644-1366
marshall@magnet.fsu.edu

Magnetic Resonance Imaging/Spectroscopy Facilities
Gainesville, FL
http://www.ufbi.ufl.edu/
http://csbnmr.health.ufl.edu/
Steve Blackband (MRI/S)
Phone: 352-846-2854
Fax: 352-392-3422
blackie@ufbi.ufl.edu

Geochemistry
Tallahassee, FL
http://www.magnet.fsu.edu/science/isotopegeochemistry/index.html
Vincent Salters
Phone: 850-644-1934
Fax: 850-644-0827
salters@magnet.fsu.edu

High B/T Facility
Gainesville, FL
http://www.magnet.fsu.edu/user/facilities/highbt/index.html
Jian-sheng Xia
Phone: 352-392-0484
Fax: 352-392-0524
jsxia@phys.ufl.edu

Pulsed Field Facility
Los Alamos, NM
http://www.lanl.gov/orgs/mst/nhmfl/welcome.html
Alex H. Lacerda
Phone: 505-665-6504
Fax: 505-665-4311
lacerda@lanl.gov